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GUIDELINES FOR SEED TRANSFER OF WESTERN WHITE PINE IN B.C. BASED ON FROST HARDINESS

By
Barbara R. Thomas, Donald T. Lester
and John Worrall*

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ABSTRACT

Thirty-four seedlots of western white pine (*Pinus monticola* Doug. ex. D. Don) were tested for frost hardiness to determine guidelines for seed transfer. Twenty-nine seedlots represented the coast and interior of British Columbia (BC), two were from coastal United States (US) and three from interior US. Detached needles were exposed to a series of freezing temperatures in a programable freezer and relative hardiness was calculated as the length of injured needle expressed as a percentage of total needle length 10 days after freezing. Seasonal progress in hardening was tested using five dates in the autumn of 1989. Seedlings were maintained at the University of British Columbia nursery.

Testing also was carried out from samples collected on separate dates from Nakusp in the BC interior and from Ladysmith, a coastal BC site. There was a statistically significant ($p<0.01$) regional difference between the BC coast and BC interior sources in all test runs, excluding the first UBC run and the Ladysmith run. In the runs where regions differed significantly, the difference in percent damage response of needles to freezing was approximately 20%. This report discusses the implications of these findings and provides recommendations for western white pine seed transfer in BC.

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PREFACE

This study was funded by the Canadian Forestry Service under the Canada-British Columbia Forest Resource Development Agreement (1985-1990) and by the NSERC/Industrial Chair in Forest Genetics and Tree Improvement. This report has been reviewed by Forestry Canada and approved for distribution. This approval does not necessarily signify that the contents reflect the views or policies of Forestry Canada.

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INTRODUCTION

Western white pine (*Pinus monticola* Dougl. ex. D. Don) (Pw) has a wide ecological amplitude (Fowells 1965), with both a coastal range, (drier coastal western hemlock zone) and an interior range in British Columbia (BC) (interior cedar hemlock zone) (Krajina *et al.* 1982) and western United States (US)(Fig. 1). Although this species has been devastated by the white pine blister rust fungus (*Cronartium ribicola* J.C. Fisch. ex. Rabenh.), introduced to Vancouver about 1910, it has recently been reinstated for commercial use (Hunt 1988, Muir 1988[1]). The research reported here is in keeping with the establishment in 1984 of a policy and management strategy for Pw in BC. The work is in direct support of a Forestry Canada project entitled 'White Pine Rust Resistance: Demonstration Plantations for British Columbia' (Meagher and Hunt 1987).

The rationale for re-introducing Pw into the commercial stream of replanting is multifold:

1. Pw is self-pruning, producing a clear white wood which is easily worked and in increasing demand by the Japanese market. Stumpage value is approximately the same as western redcedar (*Thuja plicata* Donn. (Cw)).

2. Due to its resistance to laminated root rot (*Phellinus weirii* Murr.), Pw is recommended for planting in

1 - By permission of author.

infested sites. These plantations are often mixtures with Cw and are most common where Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (Df) has been removed (Wallis 1976).

3. Favourable response to genetic selection for rust resistance has reduced the risk of loss from blister rust (Bingham *et al.* 1972, Bingham 1983).

4. Silvicultural techniques, including pruning and hazard rating of potential planting sites, can reduce risk of loss from blister rust (Hunt 1982, Hunt 1983, Hungerford *et al.* 1982).

Pw, relative to many other conifers, has shown relatively little genetic variation in phenology and cold hardiness associated with provenance. Variation predominantly has been found to be among individuals (Townsend and Hanover 1972, Steinhoff 1979, Campbell and Sugano 1989). However, rangewide sampling by Steinhoff *et al.* (1983), with isozyme analysis, revealed that the major genetic variation in Pw associated with geography is between two latitudinally distinct subgroups. The Rocky Mountain and northern Cascade ranges form the major subgroup of Pw, with a smaller subgroup in the Sierra Nevada Mountain range. The population of Pw in the southern range of the Cascade Mountains appears to be intermediate between the two subgroups. The small amount of variation which does occur within the populations north of 44^{o} latitude appears to be unrelated to geographic variables (Steinhoff *et al.* 1983, Rehfeldt *et al.* 1984).

The objective of this study was to address the specific question of Pw transferability between the coast and interior of BC, through cold-hardiness testing. Previously, frost hardiness had been tested under controlled conditions at one time only in the early phase of hardiness development. The results identified a tentative line of regional difference between the coast and interior (Rehfeldt *et al.* 1984). Further, Meagher (1988) cites an increase in damage to Idaho F_2 seedlings relative to local seedlings at a plantation in Barriere which was subjected to a severe spring frost in 1985.

This study attempts to answer the following question with respect to frost hardiness:

1. Within the species' distribution north of 44° latitude (Steinhoff *et al.* 1983), is seed origin important? The answer will influence:
    a) collection of wild-stand seed;
    b) seed planning zone and seed orchard developments;
    c) utilization of seed and parents from US breeding programs; and
    d) distribution of planting stock.

MATERIAL AND METHODS

Controlled hardiness was tested at five autumn dates using 2-year-old seedlings representing 34 seedlots maintained at the University of British Columbia's (UBC) forest nursery. The same seedlots were sampled from 3-year-old seedlings in two field plantations and tested at one date only. The plantations were at Ladysmith, BC (latitude 48°59', longitude 123°49'), a coastal environment on Vancouver Island, and at Nakusp (latitude 50°15', longitude 117°48'), in the southern BC interior. Sampling dates for the field plantations were targeted for the expected time of maximal expression of genetic differences in hardiness. Testing dates are shown in Table 1.

The BC coast was represented by 15 seedlots with three families in each of five provenances. The BC interior was represented by 14 seedlots with three families in each of four provenances and one family in each of two provenances. The United States (US) coast had two provenances of bulked seed (13 - 20 trees per seedlot), and the interior US sample consisted of wind-pollinated seed from three widely spaced trees which are presently in the Idaho Inland Empire rust resistance breeding program. (See Fig. 1 for a map of seedlot origins.)

Preliminary tests using 10 seedlots from a cross-section of origins were run prior to most complete tests of 34 seedlots to pinpoint the desired gamut of temperatures. The temperature difference at each test date did not exceed 10°C.

On each test date, four needles were collected from each of 10 different seedlings from each seedlot. The 40 needles per seedlot were divided into eight lots of five needles to be tested at four temperatures (three freezing temperatures and one control at 3°C), with two replications. Needles were tested in plastic bags. Bags were suspended in a programable-freezer and subjected to a temperature drop of 5°C per hour until the desired temperature was achieved. Samples were held at the test temperature for 1 hour prior to removal to a 3°C cold room. After removal from the freezer, all samples were held in the cold room for 24 hours to reduce the shock of recovery from freezing and to allow them to equilibrate prior to expression of injury. Injury was measured as percent damage (length of brown tissue on each needle divided by the total length of the needle and multiplied by 100), 10 days after freezing (Rehfeldt 1980). Supplementary freezing tests had shown that expression of injury was most easily observed after approximately 10 days. See Table 1 for the range of test temperatures employed at each test date.

A mean value for % damage was calculated per bag to provide two values for each test temperature and seedlot. Analysis focused on two main questions:

1. For seedlings grown at one location (UBC), is there evidence of genetic variation in frost hardiness associated with region of seed origin during the hardening period?

2. At one physiologically similar sampling time (based on the 30-year averages for the first frost for the 3 locations), is there evidence of genetic variation in frost hardiness associated with region of seed origin when seedlings are grown in three different environments?

Analysis included all samples at the regional level and only BC seedlots at the provenance-within-region and family-within-provenance level. This was due to the small sample size and lack of comparable sampling design in the US material.

Analysis of variance was carried out using SAS (1985). Primary analysis was at the regional level for the five test dates for stock grown at UBC. Regions are identified in Fig. 1. Regional means were compared by multiple range tests and orthogonal comparisons.

Data from Nakusp and Ladysmith plantations were analyzed with data from the day 66 test and day 45 test on stock grown at UBC. Again, this analysis started at the regional level, including seedlots from the US, and was then conducted at the provenance-within-region and family-within-provenance level for BC only. See Table 1 for test dates.

At all test dates, temperature was nested within date and all data from one date were combined for analysis. The initial test temperature for day 66 was not useable due to a technical problem and therefore only two test temperatures were available for analysis for this test date.

RESULTS

I. Cold hardiness over time at one location.

i. All dates, all regions

Analysis of data combined from five test dates for seedlings grown at UBC, showed that regions differed in response to controlled freezing (Fig. 2). Values presented in Figure 2 are means of relative percent damage for combined test dates since test temperatures varied for each date. Therefore, the absolute damage values for each test date can not be compared across test dates. Region 1 represents the BC coast, region 2 represents the BC interior and regions 3 and 4 represent the US coast and interior respectively (Table 1). For all dates, regional comparisons were performed both latitudinally and longitudinally. Within BC, longitudinal comparisons of coast and interior were statistically significantly different ($p<0.01$), and within the US, coast and interior were not found to be significantly different (this may be a consequence of small sample size).

Further, latitudinal comparisons showed that the BC coast and interior provenances combined were significantly different from the US coast and interior regions combined (again this may be due to the small sample size for the US). This result supports the findings by Meagher (1988) that Idaho stock may be less hardy than native interior BC sources. Although differences associated with latitude were found, no clear latitudinal trend in hardiness was evident (Fig. 3 a,b). Simmilarly, plots of injury by elevation of prevenance did not reveal clear trends.

There were no significant interaction terms in the above analysis.

ii. Individual dates, all regions

At individual test dates, the regional difference between BC coast and interior is shown to be consistent (Fig. 4). A more-detailed regional analysis shows that days 20, 45, 66 and 80 all show a significant difference ($p<0.01$) between the BC coast and BC interior with no significant difference between BC and US seedlots. Days 20 and 80 also show a significant difference ($p<0.05$) between coast (BC and US) versus interior (BC and US).

Although results from day 0 (Fig. 4) appear to support this trend, needle samples had not been divided into two replicates for testing and thus only one mean value was available for analysis for each test temperature. The precision of testing on day 0 was therefore reduced; no statistically significant differences were found. Further, this test was conducted September 7/89, prior to the time of expected maximal expression of genetic differences for cold hardiness. However, a probability of 0.12 for BC coast versus BC interior suggests that the differences are real. The difference in the mean regional value for the BC coast versus the BC interior is approximately 9% for day 0 versus 20% on average for the subsequent 4 test days.

iii. All dates, BC regions

For BC seedlots, mean injury again differed significantly between coast and interior ($p<0.05$). Provenances-within-coast and -interior regions did not differ significantly ($p=0.11$), although coastal provenances differed by up to 28% (45%-73%) and interior

provenances by 35% (30%-65%). Families-within-provenances did differ significantly ($p<0.01$), ranging between 4-41% for the coast and by 15-42.5% for the interior. The minimal number of families-within-provenances and variability of families-within-provenances could account for failure to detect statistically significant differences among provenances despite the substantial range in provenance means.

iv. Individual dates, BC regions

With individual day analysis, region was significant ($p<0.01$) for days 20 and 80, and significant at $p<0.05$ for day 45. Days 0 and 66 were not significant ($p=0.34$ and $p=0.16$ respectively). Only day 0 was significant for provenance-within-region ($p<0.05$) and family-within-provenance differed ($p<0.001$) for all days.

II. Cold hardiness at three locations.

i. All locations, all regions

Results from the two field test locations and one collection at UBC further support the findings in Figs. 2 and 4 (Fig. 5). Data from day 66 at UBC were chosen because they most closely matched the criterion for choosing collection dates at the 2 field sites ie:historical date of first frost. With all location and regional data included, there were regional differences ($p<0.01$). There was however, a significant ($p<0.05$) region x location interaction effect. When the US material was left out of the analysis, this interaction was no longer present.

Although sampling dates were chosen to coincide with the expected maximum expression of genetic variation, it is obvious

from Table 1 that it was not possible to show differences in response among seedlots through testing them at the same temperatures. With day 45 (UBC), used in the combined analysis, replacing day 66, region was significant ($p<0.0001$) as well the region x location interaction term was significant ($p<0.01$). This interaction remained significant ($p<0.05$) with the US material removed (Fig. 6).

ii. Individual locations, all regions

With individual analysis of each location, there was no significant difference between seedlots from BC and the US. The UBC (days 45 and 66) and Nakusp runs showed significant differences for the BC coast versus BC interior regions ($p<0.01$).

The Ladysmith collection showed no significant difference among regions. This could be due to the mild autumn, with the consequence that the timing of the test date did not coincide with the onset of genetic differences in frost hardiness. The trend however is the same as at the two other sites ($p=0.22$ for BC coast versus BC interior).

iii. All locations, BC regions

Again, for all locations with the BC data only (UBC days 45 and 66) , regional effects remained significant ($P<0.05$). Provenances-within-region did not differ statistically ($p=0.15$) although the range of injury for provenance means was 18.5% (61-79.5%) for coastal seedlots and 29% (48-77%) for interior seedlots. Families-within-provenance differed significantly ($p<0.01$), by 8-25% on the coast and 24-32% for families-within-interior provenances. This is in keeping with the findings of

iv. Individual locations, BC regions

For individual location analysis data only from UBC day 45 showed significant regional differences ($p<0.05$). Region was not statistically significant for UBC day 66, $p=0.16$, Ladysmith, $p=0.55$, or Nakusp, $p=0.10$, (Fig. 5, regions 1 and 2 only). As well, provenances-within-regions did not differ on any date, however families-within-provenances differed significantly on all dates ($p<0.001$).

RECOMMENDATIONS

The recommendations to be made from this study are relatively strong regarding the BC material and far from definitive regarding the US material.

Based on the tests conducted, seed origin of Pw is important. The implications of this conclusion apply to the following activities:

a) **Collection of wild-stand seed**

Coast and interior seedlots should be kept separate. Since the variation among provenances in a region is not statistically significant, seed could be combined from more than one provenance within a region.

Combining provenances within a region would make seed collection and/or parent-tree selections for breeding purposes less complicated. It would allow for more-rigorous selection within a region, however, a high degree of variability would exist within a pooled collection within a region.

b) **Seed planning zone and seed orchard development**

This study suggests that two seed planning zones may be necessary to reduce the likelihood of restocking failures due to frost damage or kill if coast-interior transfers were to be made. It must be emphasized however, that this recommendation is based solely on the response of detached needles to freeze testing. Fig. 3 shows the average difference in the % damage response

between the BC coast and BC interior to be approximately 20% (not including day 0).

An additional observation, though not part of the study objectives, was that the seedlings at the Nakusp site had been grown for 1 year (of 3) on southern Vancouver Island and appeared to respond in a consistent manner with coastal site stock.

c) Utilization of seed and parents from US breeding programs

Due to the sample size constraints in this study, the variability in response observed and illustrated in Figs. 2, 3 and 4, makes interpretation difficult. Generally, however, the trend of coastal material expressing greater damage than interior seedlots holds. Nevertheless, the interior US seedlots consistently show more damage than the interior BC seedlots. Fig. 2 suggests that US stock is generally intermediate in controlled freezing response between BC coast and BC interior seedlots.

Work by Bower (1987), suggests that the rust-resistant second-generation seedlings from the Idaho breeding program could be used in BC for increased disease resistance. The study by Bower (1987), was restricted to testing on the coast and the question is under more extensive investigation at present (Meagher and Hunt 1987). However, we recommend that a more-comprehensive set of US material be retested for response to freeze testing before recommending whether US material differs in cold hardiness from BC material.

d) Distribution of planting stock

Given that two seed planning zones are recommended, it is clear that planting stock derived from sources within a coastal or interior region should be restricted to distribution within the respective region. As stated above, however, seed likely could be bulked from provenances within a region.

It was not possible to investigate the effects of spring dehardening or to obtain useable phenology data. It is suggested that these areas be researched to substantiate or refute the above recommendations before implementation. A correlation in response to freeze testing of needles versus whole seedlings should be investigated. Work by Nilsson and Eriksson (1986) on Scots pine in northern Sweden showed that artificial freeze testing of whole seedlings can represent field performance at the population level.

SUMMARY

The results of this study support the need for coastal and interior seed planning zones within BC for Pw, based on autumn frost hardiness testing. These data support the findings of Rehfeldt *et al.* (1984), that Pw shows regional variation in frost hardiness. The advisability of incorporating US stock into the BC Pw breeding program is less clear, regarding frost hardiness response, but it appears that US stock follows similar trends to the more-rigorously tested BC material. More work needs to be conducted to clarify this question.

For a more comprehensive analysis of this study, see Thomas (M.Sc.(Forestry) Thesis in prep.).

TABLE 1 Location of sampled trees, test date, day (from Sept. 7) and test temperatures for all runs.

LOCATION	DAY	TEST DATE	TEST TEMPERATURES °C
UBC	0	Sept. 7/89	3, -7, -9, -11
UBC	20	Sept. 27/89	3, -9, -11, -13
UBC	45	Oct. 22/89	3, -11, -13, -15
UBC Nov.16[1]	66	Nov. 12/89	3, --[2] -24, -28
UBC	80	Nov. 26/89	3, -30, -35, -40
NAKUSP	Oct. 3[1]	Oct. 6/89	3, -12, -14, -16
LADYSMITH	Nov. 14[1]	Nov. 14/89	3, -22, -26, -30

1 Average date of first frost.

2 These samples were not useable due to a technical problem.

FIG. 1 Map of seedlot origins (●), natural range of western white pine (stippled area) and region delineation (numbers). (modified from Fowells 1965)

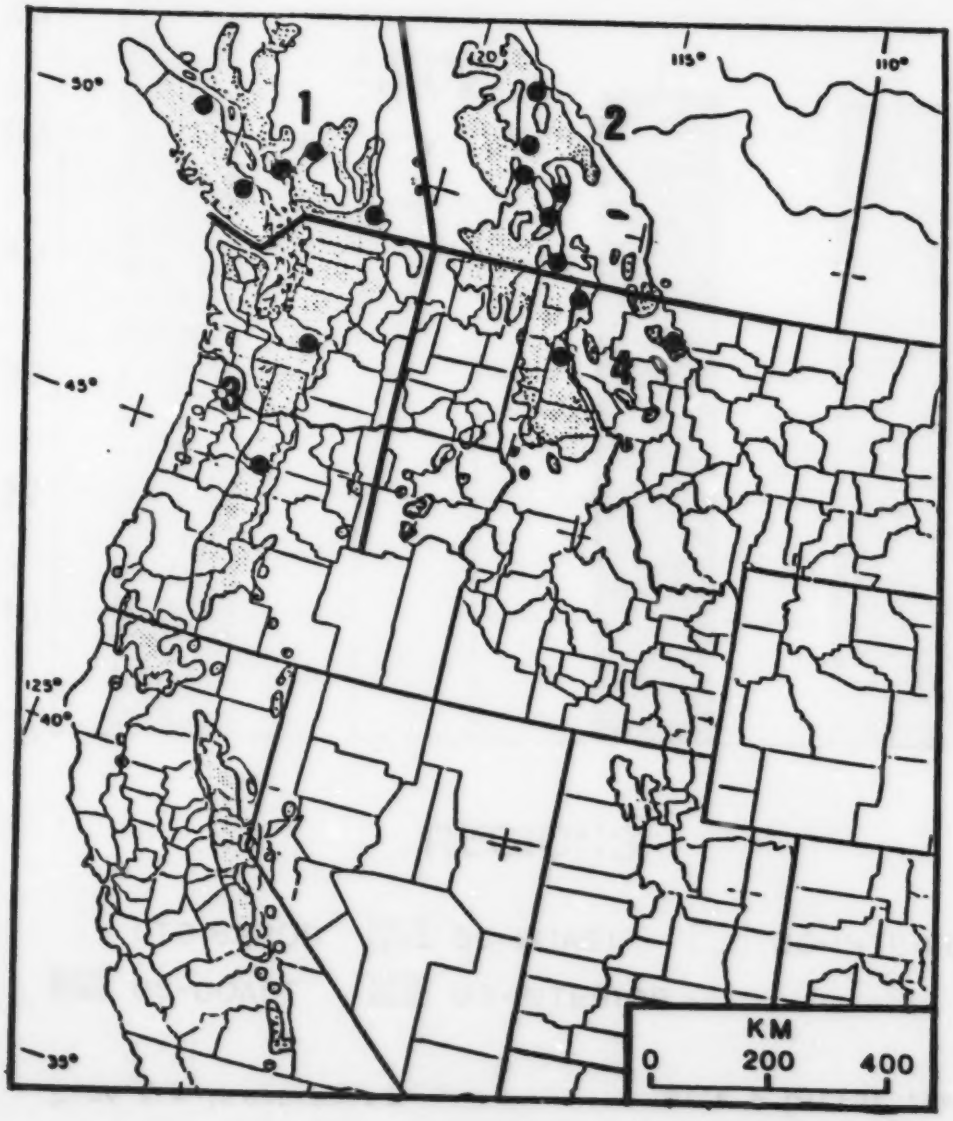
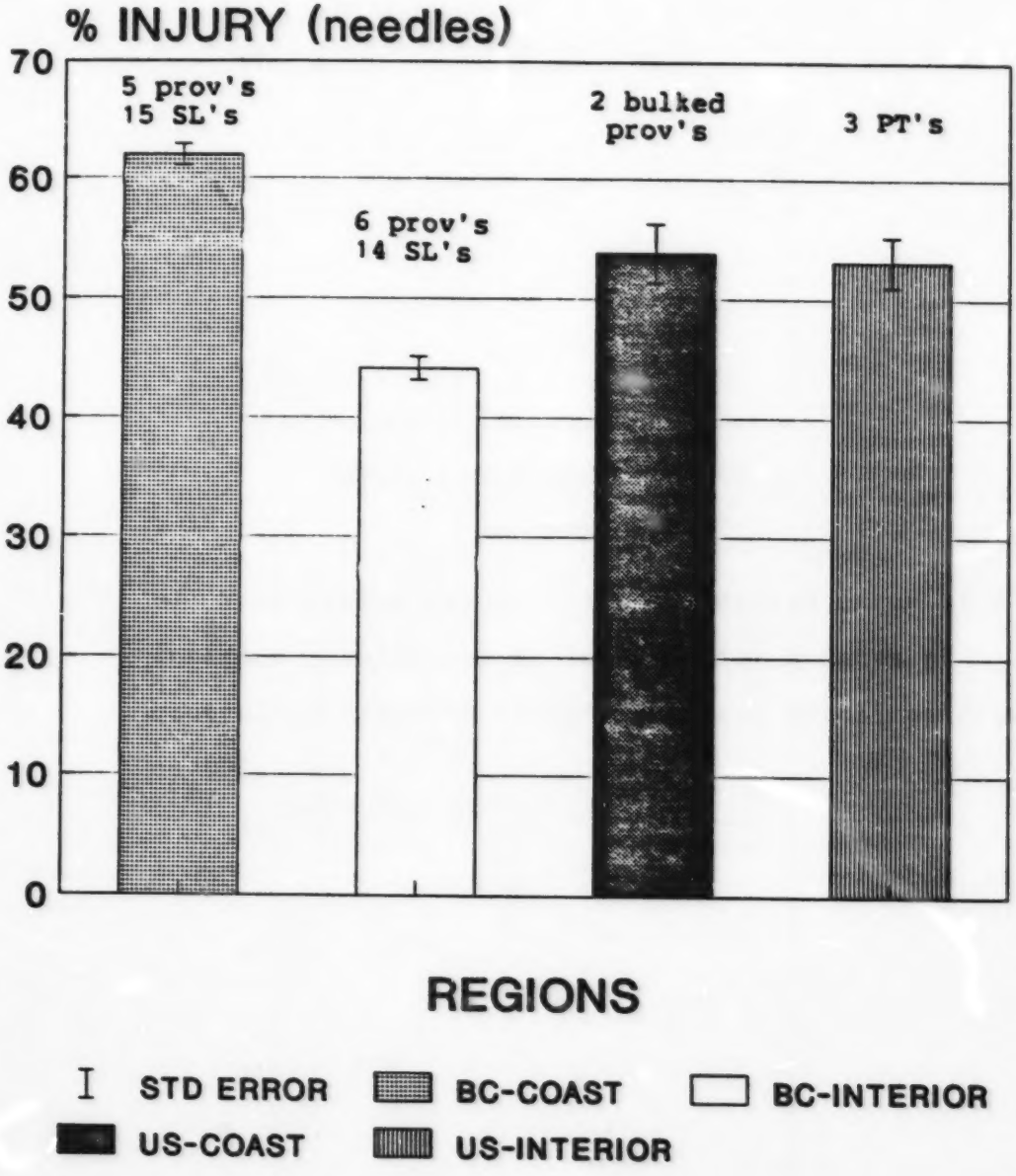


FIG. 2 Mean needle injury (%) and standard error by region for combined data from controlled freezing on 5 test dates using 2-year-old seedlings grown at UBC.

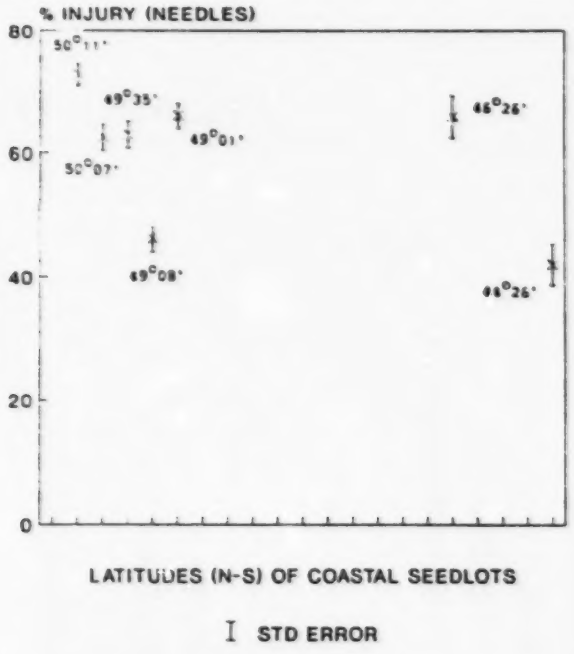


prov's = provenances

PT's = parent trees

SL's = seedlots

FIG. 3 a) Mean needle injury (%) and standard error of 7 coastal provenances by latitude for 5 dates of controlled freezing using 2-year-old seedlings grown at UBC.



b) Mean needle injury (%) and standard error of 9 interior provenances by latitude for 5 dates of controlled freezing using 2-year-old seedlings grown at UBC.

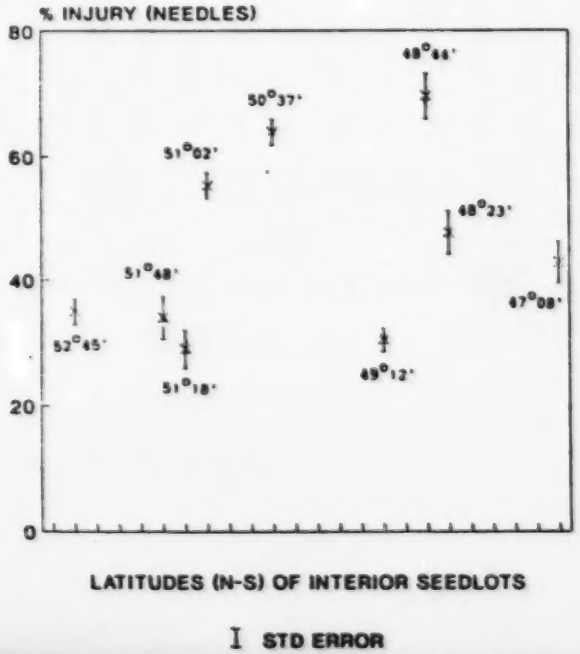
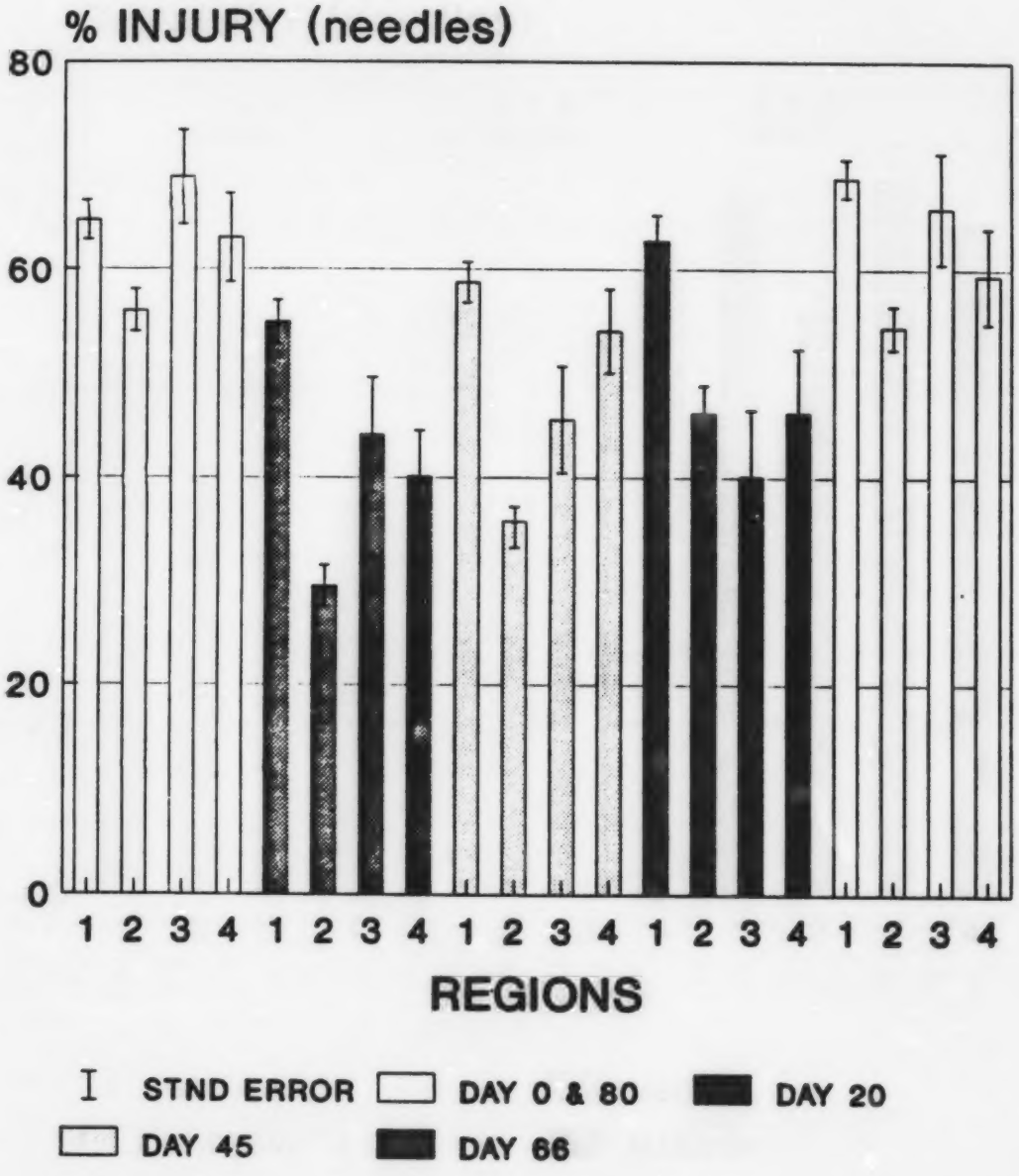
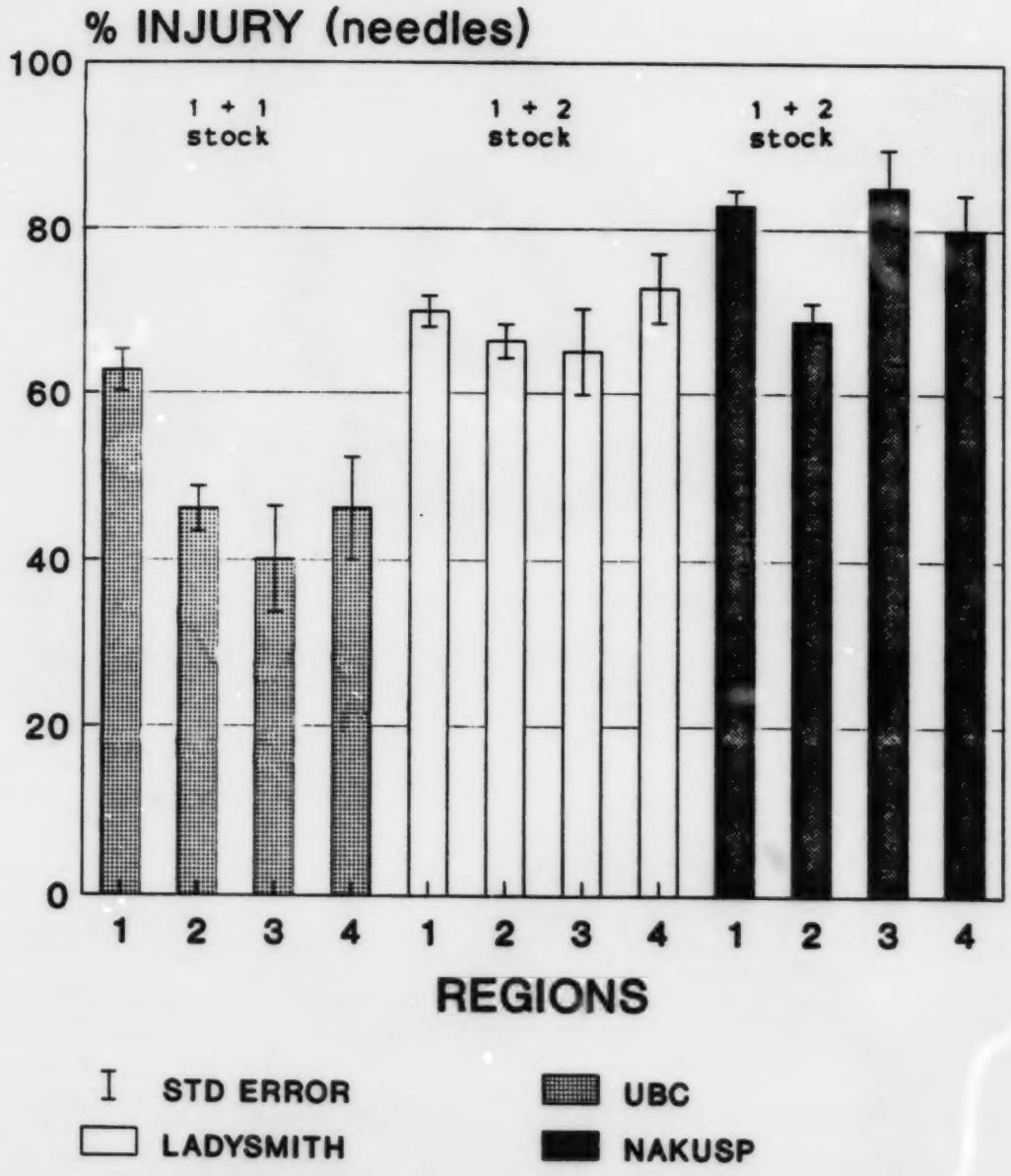


FIG. 4 Mean needle injury (%) and standard error by region for 5 dates of controlled freezing using 2-year-old seedlings grown at UBC.



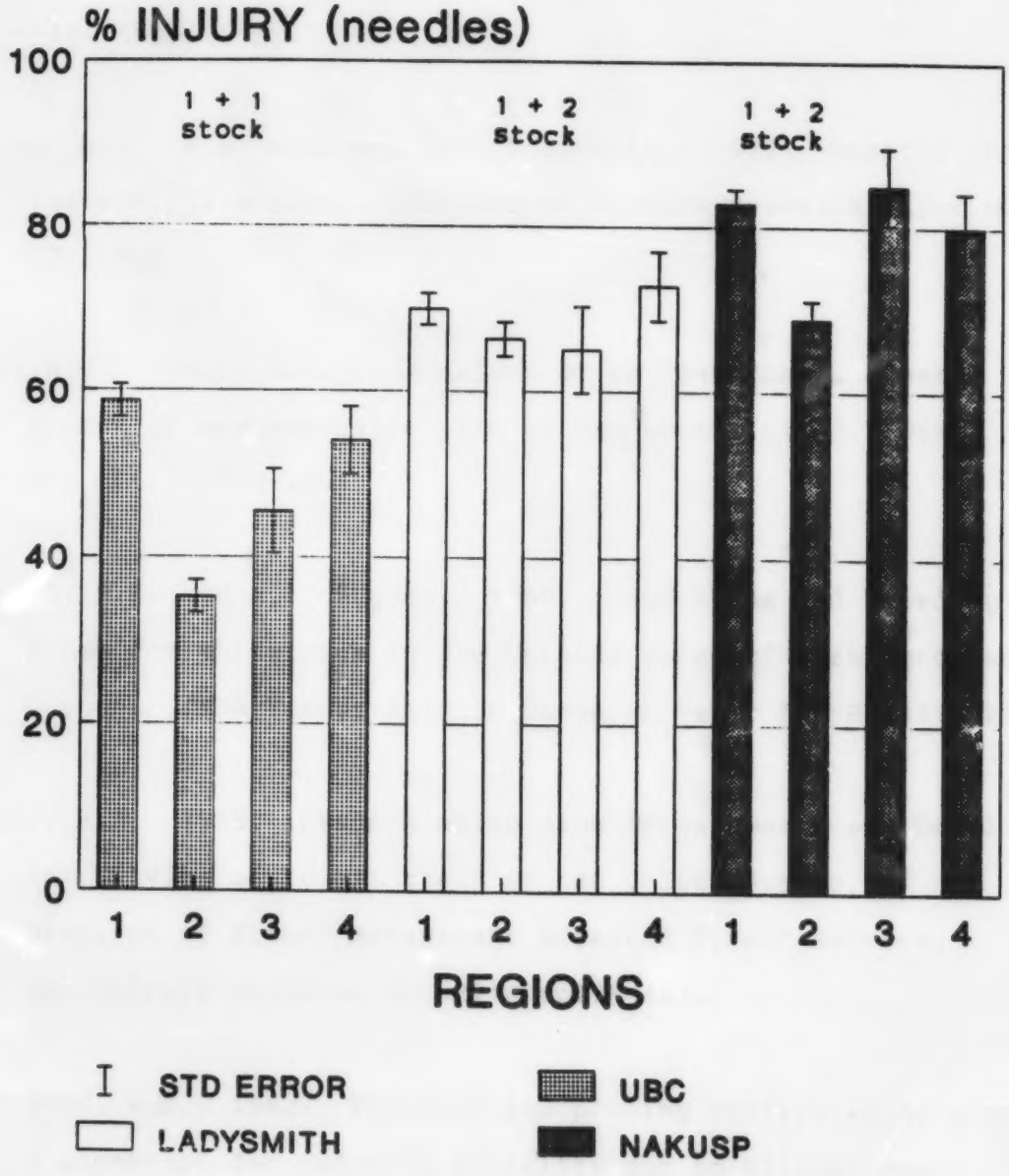
1=BC-C, 2=BC-I, 3=US-C, 4=US-I

FIG. 5 Mean needle injury (%) and standard error by region from controlled freezing using 2-and 3-year-old seedlings from UBC (day 66), Ladysmith and Nakusp.



1=BC-C, 2=BC-I, 3=US-C, 4=US-I

FIG. 6 Mean needle injury (%) and standard error by region from controlled freezing using 2-and 3-year-old seedlings from UBC (day 45), Ladysmith and Nakusp.



1=BC-C, 2=BC-I, 3=US-C, 4=US-I

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